Drell-Yan Measurements of Nucleon and Nuclear Structure with the Fermilab Main Injector: E906 Technical, Cost, Schedule and Management Review

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1. INTRODUCTION TO FERMILAB E906/DRELL-YAN

The Fermilab E906/Drell-Yan experiment will measure nucleon and nuclear structure at the parton level using Drell-Yan scattering. This experiment will use the 120 GeV/c proton beam extracted from the Fermilab Main Injector. The experiment has been approved by the Fermilab PAC. It is scheduled to begin collecting data in 2009; although, Fermilab has expressed an interest in running the experiment as soon as the spectrometer is complete.

In the Drell-Yan process, a quark (antiquark) in the beam hadron annihilates with an antiquark (quark) in the target. In the limit of large x-Feynman, only the beam quark and target antiquark terms are important; hence, Drell-Yan scattering is able to probe the antiquark sea of the target hadron. It can also measure interactions of the initial state quark in the nuclear medium. Several previous Drell-Yan experiments have already exploited these properties but were limited by statistics to rather low values of parton fractional momentum, x. At fixed x, the Drell-Yan cross section scales as the inverse of the square of the center-of-mass energy (*i.e.* approximately as $1/E_{\mathrm{beam}}$). Because of this, at the lower beam energy of the Fermilab Main Injector, the Drell-Yan cross section is a factor of seven *higher* than in previous Fermilab Tevatron (800 GeV/c beam) Drell-Yan experiments. At the same time, most backgrounds (primarily J/ψ production) scale with the square of the center-of-mass energy. As such, they will be suppressed in a Main Injector experiment, allowing for an increase in instantaneous luminosity of a factor of seven. Thus, for the same running time, a factor of almost 50 times more Drell-Yan events may be recorded. The Fermilab E906 collaboration will exploit this to make several important physics measurements at larger values of x than previously achievable.

While perturbative Quantum Chromodynamics (QCD) provides a good description of the evolution of the proton's parton distributions, it provides no clues as to their origins. With Drell-Yan's sensitivity to the antiquark distributions, it can be used to measure the ratio of anti-down to anti-up, $\bar{d}/\bar{u}$, quarks in the proton. As measured in previous Drell-Yan experiments, this ratio is far from unity for moderate values of x—indicating a significant non-perturbative component in the proton's sea. At larger values of x, the data appear to show the strengths of the $\bar{d}$ and $\bar{u}$ distributions becoming more equal, possibly indicating that the perturbatively generated sea is becoming dominant. Fermilab E906 will have the reach to study this region and determine the ratio of $\bar{d}/\bar{u}$ from measurements on liquid hydrogen and deuterium targets.

As $x \rightarrow 1$, there is considerable uncertainty in the distributions of valence quarks. In part, this is due to a lack of proton data, and in part, due to uncertainties in nuclear corrections, which are significant as $x \to 1$, even in deuterium. The absolute Drell-Yan cross section is sensitive to these high-x parton distributions in the *beam proton.* Data from the previous Drell-Yan experiment show a possible trend in which next-to-leading order cross section calculations tend to under-predict the measured cross section. This could, perhaps, be attributed to the uncertainty in the ratio $d_{\mathrm{v}}/u_{\mathrm{v}}$ as $x \to 1$. The proton-proton absolute cross section measurements from Fermilab E906 will provide the data—free of nuclear corrections—needed to determine the behavior of $4u + d$ as $x \to 1$ with good statistical precision.

When the proton is contained in a nucleus, the proton's parton distributions appear to be modified. In addition to hydrogen and deuterium, data will be collected on a variety of nuclear targets to study these changes. Pions in meson exchange models of nuclear binding should lead to an enhancement of the antiquark sea in nuclei when compared to deuterium. While this was not seen by previous Drell-Yan experiments, the large statistical uncertainty at high x allowed considerable freedom for these models. Due to the increased cross section at higher x Fermilab E906 will be able to significantly constrain these models. Absolute cross section measurements on deuterium will provide a measurement of $\bar{d}(x) + \bar{u}(x)$, a quantity so far only accessible through neutrino deep inelastic scattering cross section measurements on heavy nuclear targets. At the same time, the absolute cross section measurements on nuclear targets will determine how nuclear effects might influence the interpretation of the neutrino data.

Finally, the Drell-Yan process can be used to study the interactions of fast, colored partons traversing cold nuclei. Since the final state particles, muons, only interact electromagnetically and not strongly, only the initial state strong interactions of the incident quarks are apparent. This makes Drell-Yan an ideal laboratory to study the energy loss of partons in nuclei—a subject of considerable interest to the Relativistic Heavy Ion community. Several models have been proposed to describe the energy loss process. By comparing different nuclei, previous Drell-Yan experiments have placed limits on parton energy loss within the context of these models. Because the lower beam energy will provide both higher statistics and increased sensitivity to energy loss, this experiment will be able to measure this energy loss and quantitatively distinguish between competing models.

The *NSAC Long Range Plan* outlined a series of fundamental questions in Nuclear Physics. The measurements Drell-Yan measurement highlighted above will provide answers to the some of these, including, "What is the structure of the nucleon?" and "What is the structure of nucleonic matter?" At the same time, they will also help in interpreting data that are needed to answer the questions, "What are the properties of hot nuclear matter?" and through a better understanding backgrounds via better parton distributions "What is the new Standard Model?"

Fermilab E906 is a straight-forward extension of the earlier Drell-Yan experiments at Fermilab. The apparatus to be constructed will be very similar to that used by previous high-rate 800 GeV/c Drell-Yan experiments at Fermilab. In fact it will reuse many of the detector components and much of the electronics from these and other Fermilab experiments. The proposed apparatus will consist of two large dipole magnets and a number of tracking/triggering stations. The liquid hydrogen, liquid deuterium and solid targets will be positioned upstream of the first magnet. The first magnet, which focuses the muons produced in the target, will contain the beam dump and a thick wall of absorber material, designed to allow only muons to traverse the active detector elements. The second magnet will provide the primary momentum measurement of the muons. A total of four tracking and triggering stations will be constructed between the two magnets and after the second magnet. Because of the lower beam energy, relative to previous Drell-Yan experiments, the entire layout of the experiment must be contracted along the beam axis. This necessitates the construction of a new muon focusing magnet. The new magnet will be roughly one third as long as the magnet used by the previous Fermilab Drell-Yan experiments. Fortunately, the iron from the old magnet is available and can be reused in the new magnet; however, new coils will need to be constructed. This represents the larges part of the reconfiguration of the spectrometer. The remainder of the spectrometer upgrade will be to replace aging equipment from the previous experiment and to upgrade the trigger system and the initial tracking station to handle higher rates. There are absolutely no technical problems in completing this experiment.

This document outlines the budget, schedule and resources from DOE Office of Nuclear Physics and the NSF necessary to complete the E906/Drell-Yan measurements. Fermilab will also be playing a major role in staging this experiment. An estimate of the additional Fermilab resources is outlined in "Estimated Cost to Mount E906" by D. Christian *et al.* [1]. The collaborations specific requests for Fermilab support are given in App. A.

2. EXPERIMENTAL APPARATUS

The design of the experimental apparatus leans heavily on the collective experience of Fermilab E605, E772, E789 and E866/NuSea for the best technique to handle high luminosities in fixed target Drell-Yan experiments. The apparatus is optimized for events with large x_2 and $x_F \approx 0.2$. For scale, the muons generated by a 7 GeV virtual photon with $x_F = 0.2$ which decay perpendicular to the direction of motion (in the virtual photon rest frame) will in the laboratory have momenta of 33 GeV, an opening angle of 210 mr and transverse momenta of 3.5 GeV. A sketch of the apparatus showing trajectories for muons is shown in Figs. 1 (bend plane view) and 2. The key features of the apparatus are:

- Relatively short (<15% interaction length, L_I) targets to minimize secondary reactions in the target.
- Two independent magnetic field volumes, one to focus the high transverse momentum muons and defocus low transverse momentum muons and one to measure the muon momenta.
- A 15 L_I hadron absorber to remove high transverse momentum hadrons.
- A 30 L_I beam dump at the entrance of the first magnet.
- Zinc and concrete or iron walls for muon identification at the rear of the apparatus (located after Station 3 and between the planes of Station 4).
- Maximum use of existing equipment consistent with the physics goals.

While the lower beam energy is a great advantage in terms of cross section, background rates and statistics, it has two disadvantages relative to 800 GeV experiments.

- The corresponding lower particle energies lead to increased probabilities for muonic decay of the produced hadrons. This is partially compensated by reducing the target-to-hadron-absorber distance to 1.3–1.8 m.
- The lower energy muons multiple scatter more easily in the hadron absorber.

As will be discussed below, much of the apparatus consists of equipment recycled from previous experiments. On the part of the collaboration, the first magnet is requires a significant construction effort. Fermilab will also be devoting a significant resources to providing the infrastructure necessary for this experiment.

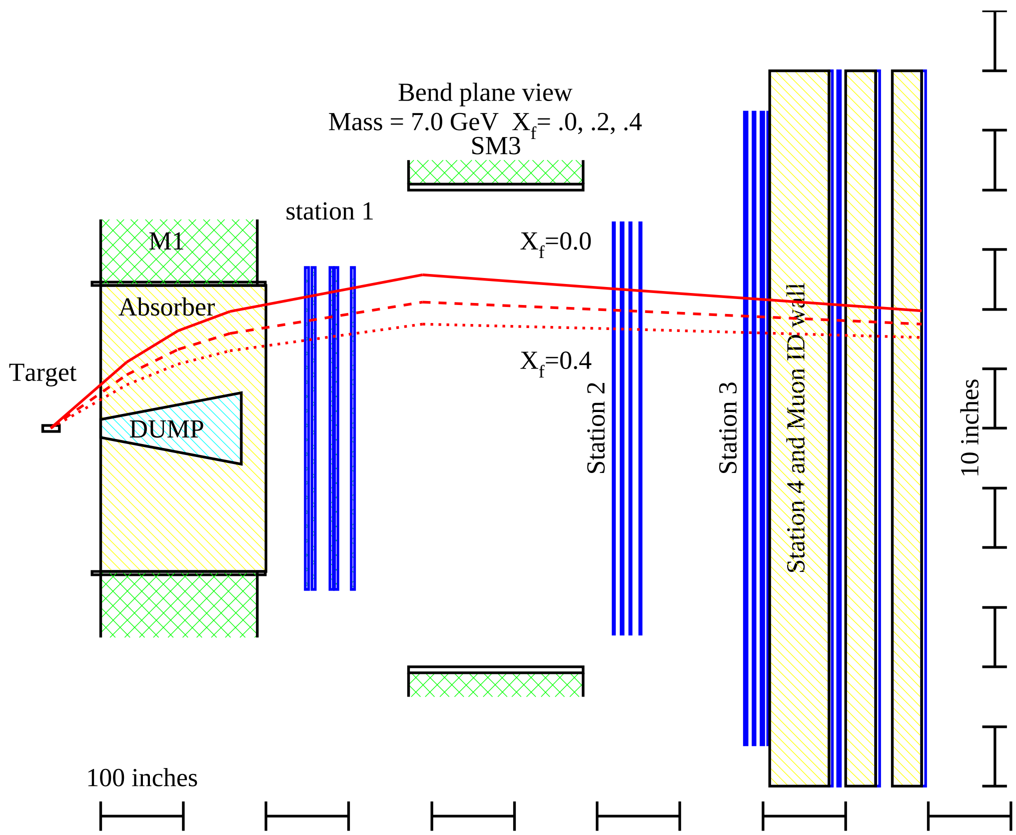

FIG. 1: Bend plane view of the trajectories of one of the two muons resulting from the muonic decay of a 7 GeV virtual photon (which has x_F of 0.0, 0.2 or 0.4) in an 8 T-m spectrometer.

2.1. Experimental Location

When first proposed, the experiment was to take place in the MEast hall at Fermilab. Since that time, however, MEast has been transformed into a Superconducting Cryo-Module Test Facility (SCMTF). Two alternative locations at Fermilab for staging this experiment have been identified at Fermilab: MWest and NM4 (also know as the KTeV building). Fermilab has developed estimates of the cost for placing the experiment in either location. In terms of the experiment, the significant difference is that in MWest, for shielding reasons, the spectrometer would bend muons vertically, sending positive muons into the ground. The beamline to NM4 (KTeV) is below grade and the spectrometer would be configured to bend horizontally, sending muons into the earth on the east and west sides of the hall. At this time, the location at Fermilab is not yet firm, but either location will work for the experiment. For this document, we have maintained the coordinate system used by the previous vertical bending Drell-Yan experiments (E866, E789, E772) with y as the bend direction

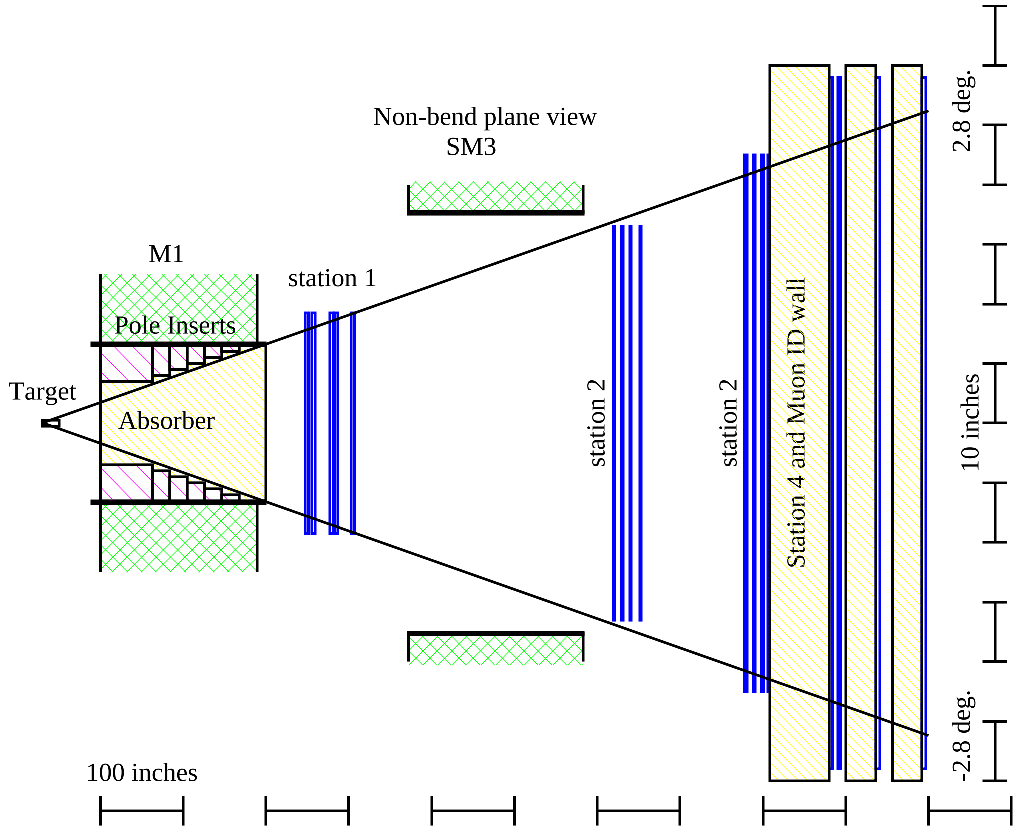

FIG. 2: Non-bend plane view in an 8 T-m spectrometer. Only muons which pass around the beam dump in the bend plane contribute to the acceptance and so the beam dump is not shown.

and x as the non-bend direction. The choice of magnets for the second, momentum measuring magnet also depends on the location. The KTeV magnet is already in NM4. Its aperture and field integral are sufficient for this experiment and it is designed to be "easily" moved within the hall. If the experiment is located in MWest, the SM3 magnet (used in previous Drell-Yan experiments) will be used. Monte Carlo acceptance and resolution studies show equal performance with either configuration.

2.2. Beam and Targets

The requirements for the beam are 2×10^{12} protons/s and a total of 5.2×10^{18} protons on target. The exact spill cycle remains to be worked out, but one possible way to achieve this in a two year run is by delivering 10^{13} protons in a 5 s slow extraction spill every minute [2]. The maximum beam spot size of 5 mm vertical by 10 mm horizontal and maximum divergence of 2 mr in each direction. The primary beam will stop in a 170" long trapezoidal copper beam dump starting with a 3" vertical height at z=0 extending to a 12" vertical height at z=170". Since the dump will absorb an average of 6400 watts of beam power, it will be water cooled with a closed loop recirculation system similar to the E866/NuSea beam dump.

The experiment will use 50.8 cm long liquid hydrogen and deuterium targets, three nuclear targets of approximately 10 gm/cm^2 thickness and a dummy liquid target cell. The targets would be remotely interchanged. In E866/NuSea, this was done every 5 spills in the 40 s between spills. A similar rotation is envisioned for E906/Drell-Yan, depending on the final accelerator cycle. The target rotation would be such that the hydrogen target will be in the beam 35% of the time; deuterium–26%, dummy liquid cell–4% and nuclear targets–35% (split between the three nuclear targets). The exact choice of nuclear targets has not been made but they are likely to be carbon, calcium or iron and tungsten. An advantage of iron would be a more direct comparison with the CCFR data. Tungsten would extend the nuclear dependence studies to a heavy nucleus, especially for the energy loss studies. Fermilab has been asked to provide the beam line instrumentation and suitable targets. The beamline and solid and cryo-targets are part of the support requested from Fermilab.

2.3. Magnets

The first magnet of the spectrometer focuses the high transverse momentum muons into the apparatus' acceptance and bends low momentum muons out of the acceptance. The optimal performance is obtained with a large-aperture, vertical-bend magnet [48" (y) by 26" (x)] whose transverse momentum, p_T, kick is approximately 2.5 GeV ($\approx$ 8.4 T-m). While reasonable Drell-Yan acceptance may be retained for lower field integrals, provided the aperture of the downstream spectrometer is large enough, the singles rates dramatically increase to an unacceptable level. Even with the present design the experiment must be prepared for 100 MHz instantaneous rates in the first set of wire chambers.

The change in beam energy (boost) from 800 GeV in E866/NuSea to 120 GeV in E906/Drell-Yan means that the 570-inch "SM12" magnet used by E866/NuSea is not appropriate for this experiment. Instead, a new magnet must be constructed. A 189" long 8 T-m large aperture magnet can be constructed using 1/3 of the iron from SM12 and new coils, following the same general principles as the SM3 magnet. The characteristics of this magnet are given in Tab. I. Iron

TABLE I: The characteristics of the proposed M1 magnet. The non-bend aperture is without the pole inserts.

Property	M1
Length	189 in
Width	95 in
Height	198 in
Bend Aperture	48 in (123 cm)
Non-Bend Aperture	26 in (66 cm)
Field Integral	8.14 T-m
Ampere-Turns	670,000
Current	2,400 Amp
Power	580 kWatt
Inlet Water Temperature	38°C
Temperature Rise	25°C
Water Flow	90 gal/min
Weight:	
Pole Inserts	9.5 t
Coils	19 t
Return Yoke	420 t
Total	450 t

inserts will provide a tapered horizontal aperture of 98 mr opening angle tailored to the aperture of the second magnet and existing down stream tracking chambers. With such a magnet, there appear to be no experimental barriers to completing the measurement proposed here.

The aperture around the beam dump in the first magnet will be filled with a graded hadron absorber. A GEANT-based Monte Carlo is being used to optimize the configuration of the absorber. One possible configuration would be 80" of graphite, followed by 40" of copper then 40" of graphite and 40" of Borated Polyethylene. The 40" of copper helps to eliminate particles which escape from the dump. The instantaneous single rates at each of the detector stations are given in Tab. II The dominant single contribution is muons produced by the decays of hadrons in the dump.

The muons will lose approximately 3.5 GeV in energy passing through the absorber and multiple scatter by an average angle of $170/p_\mu$ mr (p_μ is the muon's momentum in GeV). This level of multiple scattering will still permit acceptable virtual photon mass resolution (approximately 240 MeV) and

TABLE II: Wire Chamber Specifications and Singles Rates

Station	Type	x size (cm)	y size (cm)	wire spacing (mm)	wire orientations	Number of Channels	Expected Singles Rates (MHz)
1	MWPC	94	137.2	2.0	Y,Y',U,U',V,V'	5500	80
2	DC	137.7	149.9	10.2	Y,Y',U,U',V,V'	1000	20
3	DC	203.0	162.4	20.3	Y,Y',U,U',V,V'	700	4
4	Prop. Tubes	250.0	250.0	50.8	Y, Y', X, X'	400	8

acceptable vertex resolution to separate target and beam dump events for muon energies greater than 15 GeV. Due to the long target length relative to the target-to-absorber distance, the target position provides minimal additional track constraints for the mass measurement.

The second magnet must provide the accurate momentum determination with a large acceptance. Depending on the location chosen by Fermilab for the experiment, either SM3 (MWest) or the KTeV (NM4) magnet will be used. Both magnets offer sufficient aperture and field integral for the proposed measurements. The momentum resolution is dominated by multiple scattering and energy loss in the hadron absorber in M1 rather than by the field integral of the second magnet.

2.4. Tracking Chambers

The possibly high instantaneous rates at Station 1 require it to be able to handle rates up to 100 MHz. The E866/NuSea Station 1 drift chambers would not be able to handle these rates. Instead, Multi-Wire-Proportional-Chambers (MWPCs) with a 2 mm wire spacing will be built. Station 1 would consist of 6 planes, 2 measuring Y, and 2 each measuring U and V with stereo angles of $\pm 14.0°$. Existing E871 preamplifier-discriminator-readout would be used. Each of these wire chambers has 3 rf bucket hit resolution and would run with a fast gas (CF_4/isobutane, 80:20). The readout would consist of 5500 channels of coincidence registers. All the electronics and readout currently exist (E871 has 20000 wire chamber channels). As an alternative, the possibility of using a combination of E605 and E871 MWPCs exists, but the geometrical coverage is not optimal, with a dead zone along $x = 0$.

Tracking stations 2 and 3 would use the existing E605/E772/E866 drift chamber Stations 2 and 3. They are capable of 250 μm resolution with Ar/Ethane (50:50) gas. The stereo angle is $\pm$ 14 degrees. Existing preamplifiers and discriminators would be adequate. Some of the electronic crates in which these components are mounted were replaced prior to E866/NuSea's run in 1996. The remainder of the crates will be replaced. A 1700 channel multi-hit TDC system is required for good efficiency and rate capabilities. A more than sufficient number of LRS 3377 modules in the Fermilab PERP electronics pool and should be available [1]. Tracking for Station 4 would be done with the existing E866 Station 4 prop tubes and existing amplifiers and discriminators.

The rate dependence of the pattern recognition efficiency has been studied with Monte Carlo simulations to ensure that this choice of chamber configuration is acceptable. With the rates given in Tab. II, there is only a 4% decrease in efficiency, on the same scale as the level of rate dependent effects which were handled in E866/NuSea.

2.5. Scintillator Hodoscopes

Scintillator hodoscope planes will provide the hit information for the hardware trigger system, just as they did in E866/NuSea. Each of the four tracking station will have a y-measuring hodoscope plane associated with it. Each plane will have a total of 32 channels, separated into two groups of 16 channels for the left ($x > 0$) and right ($x < 0$) sides of the detector. There will be x hodoscope planes associated with detector Stations 1 and 2, plus two additional planes as part of Station 4. They will contain 32 channels apiece, separated into 16 channels for the lower half of the spectrometer ($y < 0$) and 16 channels for the upper half ($y > 0$). This segmentation will provide a logical division of each hodoscope plane into quadrants, allowing the trigger system to place tighter geometric constraints on the tracks than was done during E866/NuSea.

All of the scintillators within a given y hodoscope plane will be the same size. The individual scintillators within hodoscope planes X4A and X4B will all be the same angular size. In contrast, the four X1 and four X2 scintillators closest to $x = 0$ will subtend half the angular range, and the scintillators furthest from $x = 0$ will subtend 1.5 times the angular range of the X4A and X4B scintillators and the remaining X1 and X2 scintillators. This segmentation minimizes the number of hodoscope channels in Stations 1 and 2 that may be in coincidence with given channels in X4A and X4B, after accounting for the multiple scattering of the muons through the various absorbers in the spectrometer.

While many of the hodoscopes could be fabricated primarily by re-cutting and polishing the existing E866/NuSea scintillators to the sizes required for the new spectrometer, it is safer, given their age[1], to plan on constructing new scintillators and light guides for this experiment. The phototubes and bases from the existing E866/NuSea spectrometer will be reused (approximately 160 units). An additional 220 phototubes and bases are needed. These, along with spares for a total of 250 tubes, will be recovered from Argonne/HEP's contribution to the ZEUS detector at DESY when it is decommissioned in the fall of 2007. The existing E866/NuSea high voltage distribution systems or newer LeCroy units from Fermilab PREP will power the eight hodoscope planes.

For E866/NuSea, the anode signals from each phototube were sent to LeCroy 4416 leading-edge discriminators. The discriminator outputs were reshaped by custom synchronizer/stretcher modules to provide clean, single RF bucket time resolution for all hodoscope planes except Station 4, which had slightly worse than single bucket resolution. The higher background rates anticipated at the Main Injector due to the increased beam current make it very important to achieve clean, single RF bucket time resolution for all hodoscope planes. Given past experience, this should be straightforward with the existing discriminators for the hodoscopes in Stations 1 and 2, and for the X4A and X4B planes. The longest scintillators in the spectrometer, those for Y4, will be only 7" shorter than the Station 4 scintillators during E866/NuSea and phototubes will be placed on each end of these scintillators. With the double-ended readout and mean timers single bucket resolution will be achieved. Enough synchronizer/stretcher modules are available to instrument the entire new spectrometer.

2.6. Muon Identification

Final muon identification is provided with an absorber wall, 81 cm of concrete followed by 92 cm of zinc and 10 cm of lead, followed by 2 planes of streamer tubes and the X4A scintillators, then 92 cm of concrete followed by the Y4 and X4B scintillators and finally 92 cm of concrete followed by 2 planes of streamer tubes. The present E866/NuSea muon identification walls provide enough material for the smaller E906/Drell-Yan wall [3].

[1] The scintillator in Stations 3 and 4 were installed as part of E605 in 1982. The scintillator in Station 2 is from 1989, and examination scintillator left over from that installation show signs of crazing. Station 1 is of insufficient size to be reused.

2.7. Trigger

The hardware trigger system will examine the scintillator hodoscope hits to identify patterns characteristic of high mass muon pairs produced in the target. It will be conceptually similar to the system that was developed for E866/NuSea [4]. However, it will be enhanced substantially compared with the previous system, primarily to improve its ability to reject random coincidences that appear to form a candidate high p_T muon track. Such random coincidences represented over half of the apparent muon tracks observed during the E866/NuSea intermediate mass $\bar{d}/\bar{u}$ running, and the background rates in the spectrometer due to soft muons are expected to be even higher at the Main Injector. The trigger modifications will also permit the implementation of two-dimensional masking of wire chamber hits during event analysis, based on the active hodoscope roads, which will reduce the combinatorics in the wire chamber track finding. Notably, this will minimize the frequency of "hit-bank" and "track-bank" overflows, one of the sources of rate-dependent reconstruction inefficiency that we encountered during E866/NuSea. Finally, the trigger modifications will allow for the replacement of a number of custom CAMAC modules from the E866/NuSea trigger system that are now nearly 20 years old with new, more reliable and flexible units.

Electronically, the hardware trigger will consist of a single decision stage, implemented as a three-step parallel pipeline. In the first step, the outputs from the hodoscope synchronizer/stretcher modules will be routed to a set of logic modules based on commercially available FPGAs (Field Programmable Gate Arrays)[2]. The logic will identify four-fold Y1-Y2-Y3-Y4 coincidences characteristic of high p_T single muons produced in the target. Each time they observe a candidate track, they will output a bit indicating its charge, the side of the spectrometer (left or right) where it is located, the quadrant the track passed through at Y1, and the actual y location of the track at Y4. In general, Y1-Y2-Y4 triple coincidences would suffice since the spectrometer analyzing magnet is located between Stations 1 and 2, and that is in fact how candidate tracks were identified during E866/NuSea. Adding the extra constraint that the appropriate channel of Y3 must have a hit will help reject apparent tracks that actually consist of a random coincidence between hits in Stations 1 and 2 due to one muon and a hit in Station 4 due to another.

An additional FPGA logic unit will be dedicated to identifying candidate tracks originating from the target that include coincidences among at least three of the four planes X1-X2-X4A-X4B. Each

[2] In the original proposal, this was to be implemented in LeCroy 2367 modules, which are now no longer available. Fortunately, in the meantime, the cost of FPGAs has dramatically decreased and their speed has increased.

time they observe a candidate track, they will output a bit indicating the side of the spectrometer where it is located, the quadrant the track passed through at X1 and X2, and the actual x location of the track at X4A and X4B. This represents a significant upgrading of the tracking capability of the hardware trigger in the x direction, compared with E866/NuSea, and will permit full two-dimensional constraints on the tracks. It will also make continuous monitoring of the efficiency of the y hodoscopes practical. This will be important because the ability to average over long-term variations in the spectrometer efficiency between targets will be reduced at the Main Injector, since it will be difficult to change amongst the various targets as frequently as was done during E866/NuSea. In contrast, for E866/NuSea special hodoscope efficiency studies were run every few weeks. They consisted of a series of runs utilizing a special trigger configuration, sequentially turning off the high voltage on sets of x hodoscopes near the center of the spectrometer.

The second step in the trigger pipeline will combine the x and y tracking results from the first step to identify events with candidate high p_T muons present. This will be done in a pair logic modules modules, one dedicated to tracks on the left side of the spectrometer and one dedicated to tracks on the right side. The candidate muons will be characterized according to their charge, the side of the spectrometer on which they are located, and a rough measure of their p_T. Events will also be tagged that appear to have two muons with opposite charges present on the same side of the spectrometer.

In parallel with the first two steps of the main trigger sequence, OR's of all the scintillators on each side of each plane will be generated and routed to a Track Correlator [4] to generate simple cosmic ray and noise triggers for diagnostic purposes. This procedure was utilized during E866/NuSea, and the same CAMAC and NIM electronics will be reused at the Main Injector.

The final step in the trigger pipeline will generate the actual triggers, handle the experiment busy logic, and strobe the read-out electronics. This step will either be performed with one logic module or with the Track Correlators and Master Trigger OR that were designed and constructed for the E866/NuSea hardware trigger [4]. The primary physics trigger will consist of a coincidence between two candidate $x-y$ tracks of opposite charges, on either the same or opposite sides of the spectrometer. If the background trigger rate due to low mass muon pairs is higher than desirable, a rough measurement of the p_T for the two muons from the previous step may be added to provide a crude effective mass cut on the muon pair in hardware. A similar procedure, but with less granularity than anticipated with the new trigger system, was adopted for several of the data sets taken during E866/NuSea. It reduced the raw trigger rate during the E866/NuSea intermediate mass $\bar{d}/\bar{u}$ data taking by a factor of three, with essentially no reduction in efficiency for the Drell-Yan muon pairs of interest. Two triggers will be used to determine the rate of random coincidences between two muon tracks in the same RF bucket, both of which originate from the target and, thus, are indistinguishable from a real Drell-Yan muon pair. One of these triggers will record events that contain two muons of the same charge when they are located on opposite sides of the spectrometer, while the other will record a prescaled set of single-muon events. E866/NuSea has demonstrated that an excellent simulation of the random coincidence background can be obtained by combining muons from single-muon triggers into pairs, then normalizing their number to the observed rate of like-sign coincidences. Two additional triggers will select prescaled samples of events that contain a candidate track in either the x or y direction, but not necessarily both. The events with x tracks will be used to monitor the absolute efficiencies of the y hodoscopes, and the events with y tracks will be used to monitor the absolute efficiencies of the x hodoscopes. The last trigger will provide a luminosity-weighted read-out of all detector elements during random RF buckets, independent of the status of any of the spectrometer hodoscopes. This will be used to provide an unbiased measure of the background occupancy rates throughout the spectrometer, which are very important for estimating rate-dependent reconstruction inefficiencies.

2.8. Data Acquisition System

Unlike most of the spectrometer, the data acquisition system will be a departure from the previous linage of Drell-Yan experiments. We plan on implementing the CODA DAQ system for this experiment. A number of the collaborators have experience with this system from work at JLab. The signals from the Station 1 MWPC's, Station 4 Prop tubes and all hodoscopes will be readout with NEVIS electronics and latches into VME in the same manor as the E871 experiment. Because they are to operate in a high rate environment, the drift chambers will be read out with multi-hit TDC's which precludes using the TDC's from the E866/NuSea readout system. As noted in Sec. 2.4 E906/Drell-Yan plans to use LeCroy 3377 multi-hit TDC modules which are available from Fermilab PREP. The FERA bus on these TDC's will be readout into a VME based processor operating as a ROC for the CODA system.

As an (already achieved) alternative, most of readout requirements for the proposed experiment can be met by the front end system that has been assembled for Fermilab experiment E871, which, while it will be over 10 years old when E906/Drell-Yan runs, is available for use by E906/Drell-

Yan [5]. The E871 system will provide a high speed readout path for the MWPC's, hodoscopes and proportional tubes configured here. Multi-hit TDC's and the appropriate interface connection to the Processor Bus to read out the drift chambers will be added.

2.9. Analysis

The analysis of the data accumulated in these measurements should be straightforward, both in offline production and for online monitoring. The analysis will be similar to that done for E866/NuSea and would employ a small number of Linux PC's. An estimate of the scope of the analysis task can be made from the upper limit trigger rate of 1 kHz, estimated event size of 1.5 kB, and a compute time per event of 20 ms/event (on an 180 MHz HP PA8000 used in the E866/NuSea analysis) based on analysis of data in E866/NuSea. Scaling with floating point performance to a Pentium-based processor (a current "commodity" PC) one or two of these CPU's should be able analyze the data in near real-time.

Since the planned detector system would be conceptually similar to that used in E866/NuSea, the analysis algorithms from E866/NuSea should be applicable to the new experiment. Therefore, much of the old code will be reused. Since much of the raw data format will different the data unpacking parts of the code would probably be rewritten in C or C++, while other parts that need not change may remain in FORTRAN. Given the speed of current PC's it will probably not be necessary to consider parallel processing of data on the Fermilab farms; although, this capacity was used by E866 and will be maintained in the new analysis code.

3. COST, SCHEDULE AND WORK BREAKDOWN STRUCTURE

Funds are requested over three years for the completion of the magnet and spectrometer upgrades, with the bulk of the money in the second year (FY2008). Design work on the new magnet has already begun and is expected to be finished in Spring, 2007. The coils will then be fabricated in 2008 and the magnet assembled at Fermilab in December, 2008 to January, 2009. After the new magnet is in place, the spectrometer detector components will be moved into place. This will allow the experiment to begin data collection in May or June 2009. The schedule for the fabrication of the new coils, assembly of the magnet and spectrometer detector upgrades is completely funding driven through the beginning of FY2008. The itemized cost for the experiment is shown in Tabs. III and

IV. The Gantt chart for the new magnet and for the spectrometer upgrade are shown in Figs. 3, 4 and 5.

3.1. Work Breakdown Structure

This section describes the work breakdown structure for the *non-Fermilab* elements of this experiment. For planning purposes, it was assumed that money requested for FY2007 would be available by March 2007; that funds requested for FY2008 would be available by January, 2008 and likewise money requested for FY2009 would be available by January 2009.

1 E906 Magnet Construction

Coils for the new focusing magnet represent the bulk of the funds requested for this experiment. The coils will be designed by Argonne and fabricated by an outside vendor. Preliminary design work for these coils has already begun. J. Jagger is leading this effort at Argonne. The magnet will then be assembled by Fermilab using the new coils and the flux return yoke from the old SM12 magnet.

1.1 Design

1.1.1 Coil Design

Complete design of pair of 7 layer window frame coils, including utility connections (power and water) and insulation. Preliminary work is already.

Lead Institute:	Argonne
Critical Path:	No
Duration:	6 Months
Start Date:	Oct. 2006
Cost:	$32,000
Resources:	Magnet Engineering, Magnet Design and Drafting

1.1.2 Conductor Specification

The magnet will use 1.6 in square hollow aluminum (1350 alloy) conductor.

Lead Institute:	Argonne
Critical Path:	No
Duration:	1 Month
Start Date:	Mar. 2007
Cost:	$9,000
Resources:	Magnet Engineering, Magnet Design and Drafting

1.1.3 Field Simulation

Basic field calculation have been completed. This simulation will ensure that the

TABLE III: The required funding profile for construction of the focusing magnet by fiscal year and task. The "Base Cost" is in 2006 dollars and is exclusive of contingency and overhead. All other costs include contingency, overhead and escalation at the rates listed. All numbers were rounded to the nearest $1,000.

Task	Institute	Base Cost	Contin-gency	Over-head	Esca-lation	FY2007	FY2008	FY2009	Total
Magnet Design:									
Coil Design	Argonne	$21,000	12%	37.6%	1.00	$32,000			$32,000
Conductor Sec	Argonne	$6,000	12%	37.6%	1.00	$9,000			$9,000
Pole Tip Design	Argonne	$8,000	12%	37.6%	1.00	$12,000			$12,000
Assembly Drawings	Argonne	$12,000	12%	37.6%	1.00	$19,000			$19,000
Supervision of Fabrication	Argonne	$40,000	6%	37.6%	1.03		$60,000		$60,000
Conductor Purchase	Argonne	$267,000	20%	9.9%	1.03		$363,000		$363,000
Coil									
Tooling, Design and Setup	Argonne	$207,000	21%	9.9%	1.03	$283,000			$283,000
Coil Fabrication	Argonne	$482,000	21%	9.9%	1.03		$661,000		$661,000
Delivery	Argonne	$20,000	13%	9.9%	1.03		$26,000		$26,000
Assembly									
Pole Tip Fabrication	Argonne	$42,000	14%	9.9%	1.03		$54,000		$54,000
Magnet Fittings, Core	Argonne	$55,000	14%	9.9%	1.03		$71,000		$71,000
DOE Total Cost						$355,000	$1,235,000		$1,590,000

TABLE IV: The required funding profile for the upgrade of the spectrometer magnet by fiscal year and task. The “Base Cost” is in 2006 dollars and is exclusive of contingency and overhead. All other costs include contingency, overhead and escalation at the rates listed. All numbers were rounded to the nearest $1,000.

Task	Institute	Base Cost	Contin-gency	Over-head	Esca-lation	FY2007	FY2008	FY2009	Total
Hodoscopes									
PMT Quality Control	Abilene, Ill.	$2,000	7%	9.9%	1.03		$2,000		$2,000
Station 1 & 2	Illinois	$13,000	13%	0.0%	1.03		$16,000		$16,000
Station 2 & 3	Abilene	$120,000	22%	0.0%	1.03		$151,000		$151,000
Tracking									
Station 1	Colorado	$140,000	18%	0.0%	1.06		$170,000		$170,000
Station 2	Rutgers	$3,000	29%	0.0%	1.06		$4,000		$4,000
Station 3	Rutgers	$3,000	29%	0.0%	1.06		$4,000		$4,000
Station 4	Los Alamos, Rutgers	$5,000	29%	0.0%	1.06		$7,000		$7,000
St. 1 Gas	Argonne, Fermilab	$2,000	15%	9.9%	1.06		$3,000		$3,000
St. 2, 3 & 4 Gas	Argonne, Fermilab	$10,000	15%	9.9%	1.06		$13,000		$13,000
Trigger									
Design	Rutgers	$40,000	25%	0.0	1.00	$50,000			$50,000
Prototype	Rutgers	$20,000	25%	0.0	1.03		$26,000		$26,000
Revision/Testing	Rutgers	$10,000	25%	0.0	1.03		$13,000		$13,000
Fabrication	Rutgers	$10,000	25%	0.0	1.06			$13,000	$13,000
DAQ									
CODA Setup	Argonne	$30,000	19%	9.9	1.03		$40,000		$40,000
FERA Readout	Argonne	$10,000	29%	9.9	1.03		$15,000		$15,000
DOE Total							$394,000		$394,000
NSF Total						$50,000	$70,000	$13,000	$133,000

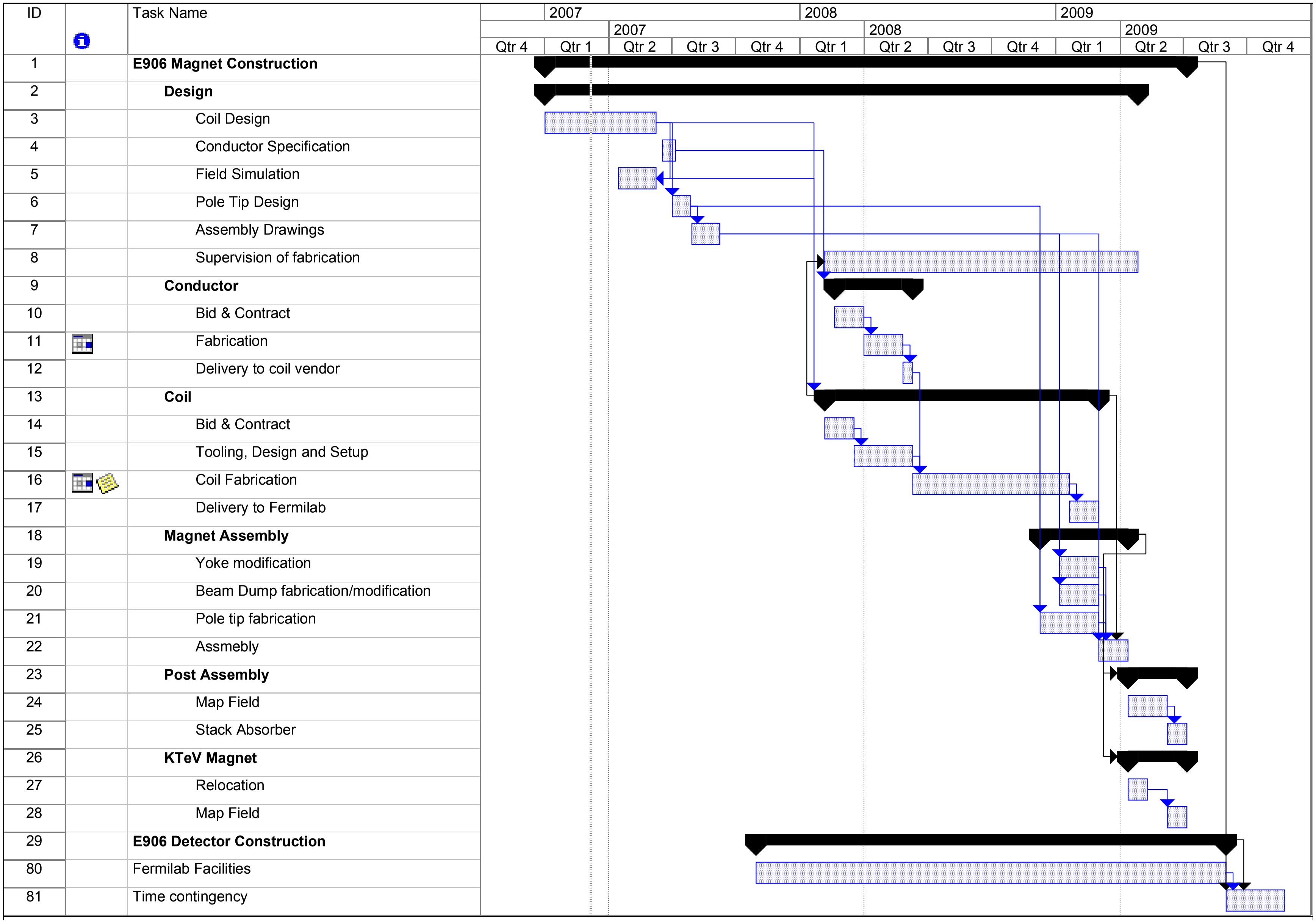

FIG. 3: Gantt chart for completion of the E906 spectrometer magnet.

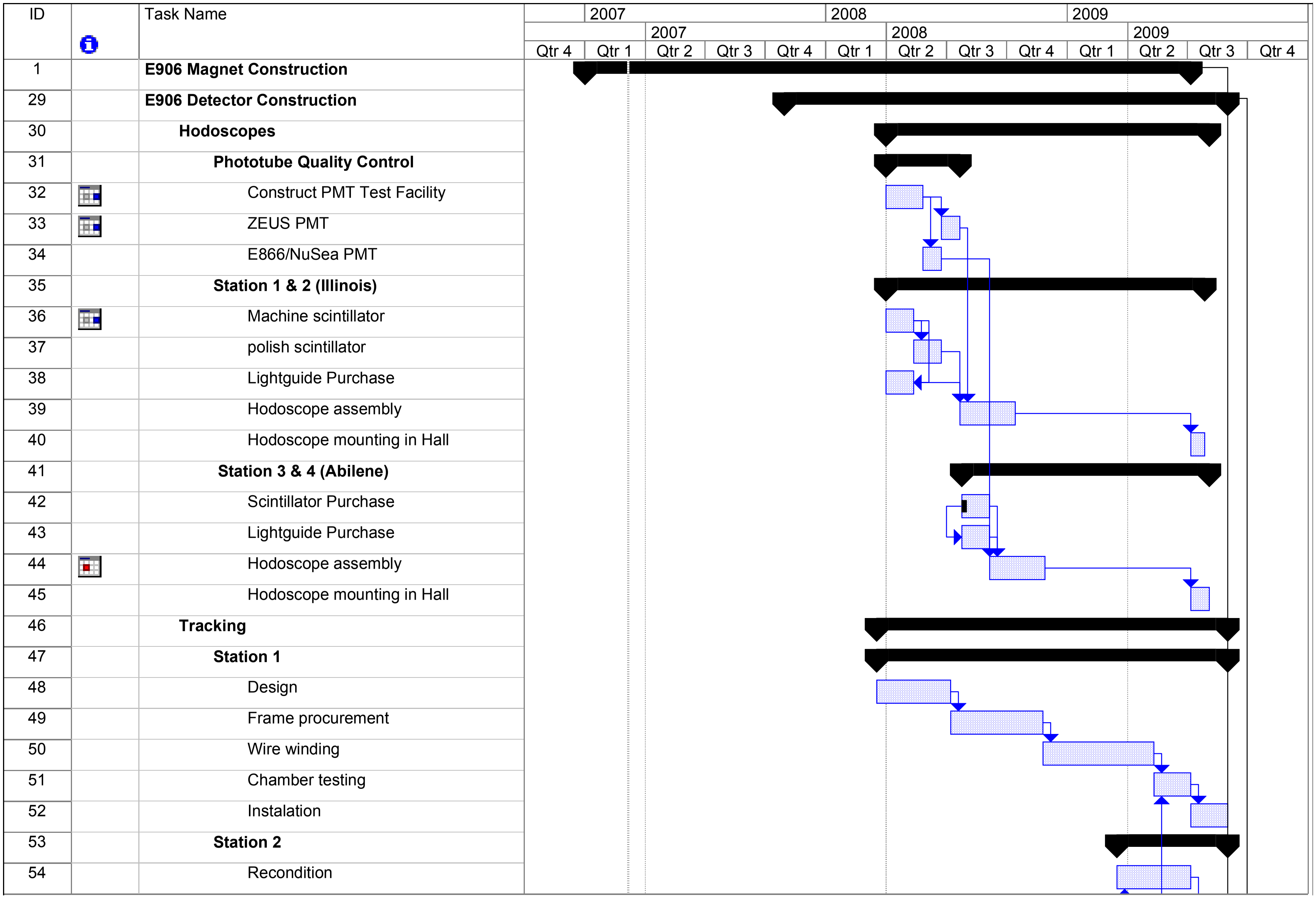

FIG. 4: Gantt chart for completion of the E906 spectrometer upgrades.

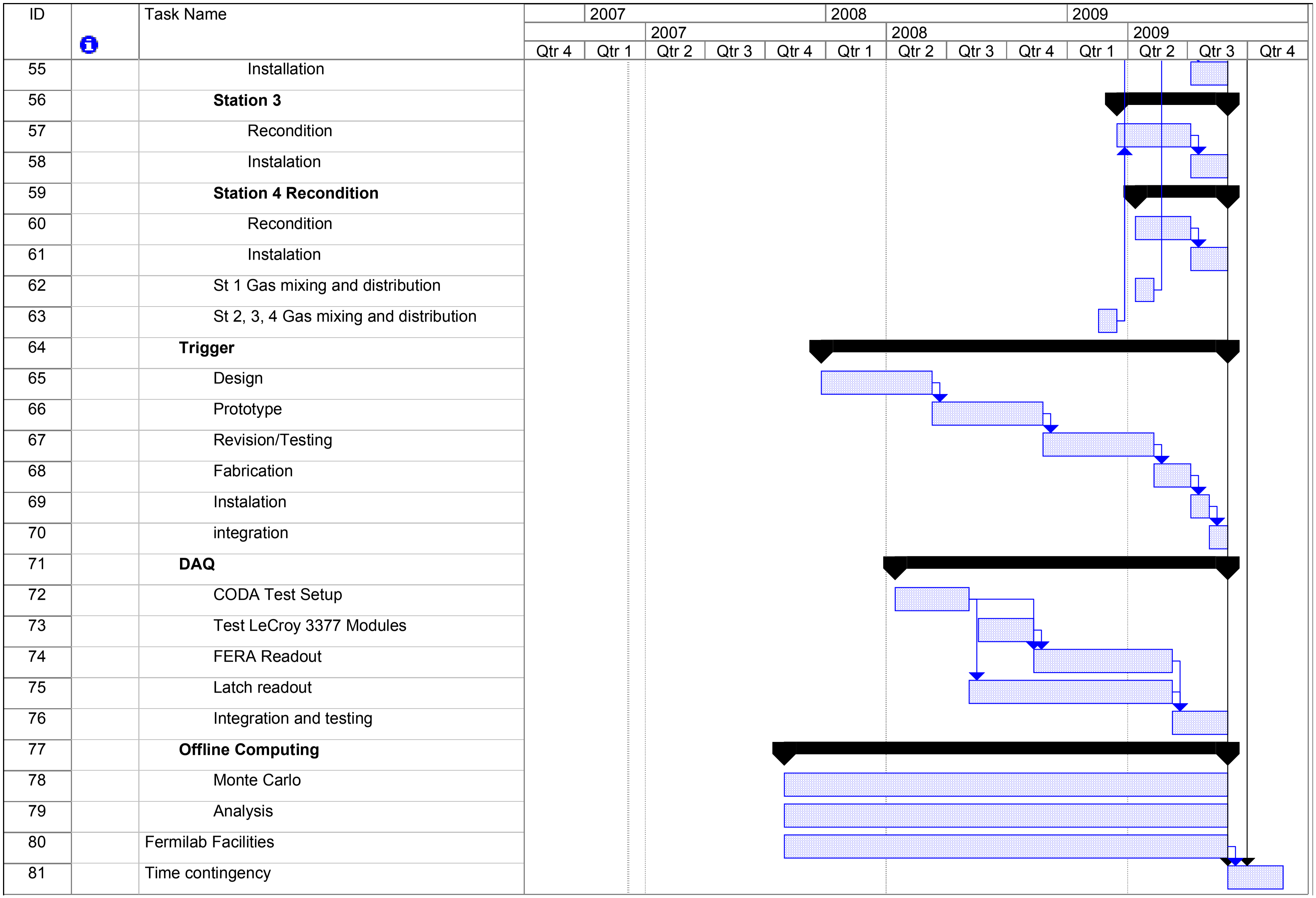

FIG. 5: Gantt chart (cont.) for completion of the E906 spectrometer upgrades.

magnet and pole tips as designed will deliver the expected field. The effort for this task will be provided by physicists within the collaboration (Argonne and Fermilab).

Lead Institute:	Argonne
Critical Path:	No
Duration:	2 Months
Start Date:	Jan. 2007
Cost:	
Resources:	

1.1.4 Pole Tip Design

The magnet will use tapered pole pieces. This task is only for the design of these pole pieces. Fabrication is in 1.4.3.

Lead Institute:	Argonne
Critical Path:	No
Duration:	1 Month
Start Date:	Apr. 2007
Cost:	$12,000
Resources:	Magnet Engineering, Magnet Design and Drafting

1.1.5 Assembly Drawings

Final assembly drawings for the magnet, pole tips and beam dump. These may be somewhat more complicated in the case of a vertical bend magnet if the experiment is located in MWest.

Lead Institute:	Argonne
Critical Path:	No
Duration:	1.5 Months
Start Date:	Nov. 2007
Cost:	$19,000
Resources:	Magnet Engineering, Magnet Design and Drafting

1.1.6 Supervision of Fabrication

Lead Institute:	Argonne
Critical Path:	No
Duration:	16 Months
Start Date:	Nov. 2007
Cost:	$60,000
Resources:	Magnet Engineering

1.2 Conductor

Purchase aluminum conductor for delivery to coil fabrication vendor. (This does not apply if Everson Tesla is selected as the coil fabrication vendor, since the conductor was included their budgetary estimate.) Bids will be solicited in late FY2007 and the purchase is timed to take place with FY2008 money. This matches time estimates from Sigma Phi on estimated initial tooling and setup time for coil fabrication. The estimate is based on a quote from Alconex Specialty Products dated Oct. 2006.

Lead Institute:	Argonne
Critical Path:	No
Duration:	6 Months
Start Date:	Nov. 2007
Cost:	\$362,000
Resources:	Magnet Engineering, Magnet Design and Drafting (included in 1.1.2 and 1.1.6)

1.3 Coil

In fall 2005, preliminary drawing for the coils were sent to five possible vendors for budgetary estimates. Four responded with estimates. Three of these vendors were contacted for updated estimates for this review (Oct. 2006): Sigma Phi, Everson Tesla and Alpha Magnetics. Everson Tesla and Sigma Phi's estimates were substantially similar, once additional shipping from France and the conductor cost were added to the Sigma Phi estimate. Alpha Magnetics' estimate was somewhat lower. The coil will be fabricated at the most economical vendor, but for the purpose of this estimate, the highest estimate of these three was chosen, Sigma Phi (converted from euro's at 1 euro = \$1.30). The three vendors not specifically divide the funding into the three categories below, but did have similar funding profiles. The money requested for this purchase is split over two fiscal years, FY2007 and FY2008. As this is *the* critical path element and the schedule is funding limited until the completion of these coils, having the money for this and the conductor purchase (1.2) could cut up to 5 months from the project's duration. The time estimates are also taken from the Sigma Phi budgetary estimate. Everson Tesla's delivery time estimate was half of Sigma Phi's. Alpha Magnetic did not provide a delivery time estimate.

1.3.1 Bid and Contract

This is a time allowance for bidding and letting the contract for coil fabrication

Lead Institute:	Argonne
Critical Path:	Yes
Duration:	1.5 Months
Start Date:	Nov. 2007
Cost:	
Resources:	Magnet Engineering, Magnet Design and Drafting (included in 1.1.6)

1.3.2 Tooling Design and Setup

Both Everson Tesla and Sigma Phi's estimates required an initial payment, with Everson Tesla specifically designating this for tooling. This money was included in the FY2007 request.

Lead Institute:	Argonne
Critical Path:	Yes
Duration:	3 Months
Start Date:	Dec. 2007
Cost:	$283,000
Resources:	Magnet Engineering

1.3.3 Fabrication

We are planning on having the vendor selected, tooling built and ready to used by the start of FY2008, when the money for this purchase is requested. If this money were available in FY2007, this could save the experiment several months.

Lead Institute:	Argonne
Critical Path:	Yes
Duration:	8 Months
Start Date:	Mar. 2008
Cost:	$661,000
Resources:	Magnet Engineering (included in 1.1.6)

1.3.4 Delivery to Fermilab

This assumes delivery from Sigma Phi in France to Argonne. Naturally delivery from a domestic vendor will be less expensive (only $7,000-$9000) and will be considered.

Lead Institute:	Argonne
Critical Path:	Yes
Duration:	1.5 Months
Start Date:	Oct. 2008
Cost:	$26,000
Resources:	

1.4 Magnet assembly

1.4.1 Yoke modification

The yoke will be constructed from pieces of the old SM12 yoke. Because the weight of these blocks exceeds the capacity of the crane in either KTeV Hall or MWest, they will need to be cut. Additional modification are necessary because the gap of the new magnet is approximately 10 in narrower than SM12. The cost of these modifications is included in the estimated Fermilab impact.

Lead Institute: Fermilab
Critical Path: No
Duration: 2 Months
Start Date: Oct. 2008
Cost:
Resources:

1.4.2 Beam dump modification/fabrication

Several options are being considered by Fermilab for the beam dump, including modifying the existing (but radioactive) bump, using the existing dump but with larger pole pieces or fabricating a new dump. This cost is included in the estimated Fermilab impact.

Lead Institute: Fermilab
Critical Path: No
Duration: 2 Months
Start Date: Oct. 2008
Cost:
Resources:

1.4.3 Pole tip fabrication

Tapered pole pieces are reasonably straight forward, large blocks of machined steel.

Lead Institute: Argonne
Critical Path: No
Duration: 3 Months
Start Date: Sep. 2008
Cost: $54,000
Resources:

1.4.4 Magnet Fittings, Core and Assembly Aids

All the additional water fittings and electrical connection flags not included in 1.3 above. This includes the cost of the inner supports to hold the coils during the assembly if the magnet is mounted as a vertical bending magnet in MWest. These costs would be reduced by locating the experiment in NM4 (KTeV).

Lead Institute: Argonne
Critical Path: No
Duration: 2 Months
Start Date: Aug. 2008
Cost: $71,000
Resources:

1.4.5 Assembly

Fermilab is responsible for the assembly of the magnet with the coils and pole tips from

Argonne. This cost is included in the Fermilab impact statement.

Lead Institute: Fermilab
Critical Path: Yes
Duration: 1.5 Months
Start Date: Dec. 2008
Cost:
Resources:

1.5 Post assembly magnet activities

1.5.1 Magnet field mapping

Map field of M1 magnet after assembly using Ziptrack. Primary effort will come from Argonne physicists and support staff.

Lead Institute: Argonne
Critical Path: Yes
Duration: 2 months
Start Date: Jan. 2009
Cost:
Resources: Fermilab Ziptrack

1.5.2 Stack hadron absorber

To minimize hadrons in the remainder of the spectrometer, the M1 magnet aperture is filled with a combination of carbon, copper and borated polyethylene. These must be put in place after the field of the magnet has been mapped. This task will involve effort from the entire collaboration.

Lead Institute: Argonne
Critical Path: Yes
Duration: 1 month
Start Date: Mar. 2009
Cost:
Resources: Collaboration labor

1.6 KTeV/SM3 Magnet

1.6.1 Magnet relocation and/or assembly

Move KTeV Magnet to appropriate location (or assemble SM3 if the experiment is located in MWest). The KTeV magnet is designed to be "easily" moved (for a several hundred ton magnet).

Lead Institute: Fermilab
Critical Path: No
Duration: 1 month
Start Date: Jan. 2009
Cost:
Resources: Fermilab support

1.6.2 Magnet field mapping

Map field of M2 magnet (either KTeV or SM3) using Ziptrack. Primary effort will come from Argonne physicists and support staff. Field maps already exist of the KTeV magnet.

Lead Institute:	Argonne
Critical Path:	Yes
Duration:	2 months
Start Date:	Mar. 2009
Cost:	
Resources:	Fermilab Ziptrack

2 E906 Spectrometer Upgrade

2.1 Hodoscopes

E906 will be replacing the E866 hodoscope material. The primary reason for this is the age of the material, some dating from E605 in 1982. Upon inspection of some left over material from the 1989 upgrade of Station 2, significant crazing was discovered in some of the material. In the analysis of the E866 absolute cross section data large efficiency corrections (up to 20%) were necessary for some specific hodoscope elements.

2.1.1 Phototube Quality Control

E906 will require 384 photomultiplier tubes. Approximately 160 will be reused from the E866 hodoscope array (double ended readout is being added to hodoscope stations 3 and 4). An additional 250 phototubes will be recovered from the Argonne HEP contribution to the ZEUS experiment at DESY. These tubes will need to be tested before use; although no problems are expected.

Lead Institute:	Abilene, Illinois
Critical Path:	No
Duration:	4 Months
Start Date:	Jan. 2008
Cost:	$2,000
Resources:	Photomultiplier Test Facility

2.1.2 Station 1 & 2

The scintillator for hodoscope stations 1 and 2 will be taken from the HERMES muon hodoscopes. It will need to be re-cut and polished before use in E906. New light guides will be fabricated.

Lead Institute:	Illinois
Critical Path:	No
Duration:	5 Months
Start Date:	Jan. 2008
Cost:	\$15,000
Resources:	

2.1.3 Station 3 & 4

The scintillator for hodoscope stations 3 and 4 will be purchased new. Estimates for the cost of new scintillator come from a quote for "diamond milled" scintillator from Eljen Technologies in Texas from 2002 with materials inflated by 40% (cost of hydrocarbons) and milling inflated by 3%/year. A new quote has been requested but not yet received.

Lead Institute:	Abilene
Critical Path:	No
Duration:	5 Months
Start Date:	Apr. 2008
Cost:	\$151,000
Resources:	Illinois or Fermilab scintillator shop

2.2 Tracking

2.2.1 Station 1

New MWPC's will be constructed for station 1 to handle the expected rates. These estimates are assuming the use of a wire winding facility at Fermilab with labor primarily supplied by the collaboration

Lead Institute:	Colorado
Critical Path:	No
Duration:	18 Months
Start Date:	Jan. 2008
Cost:	\$170,000
Resources:	Fermilab Wire Winding Facilities

2.2.2 Station 2

E906 will reuse the E866 Tracking Station 2. This task will be done in parallel with 2.2.3.

Lead Institute:	Rutgers
Critical Path:	No
Duration:	6 Months
Start Date:	Dec. 2008
Cost:	\$4,000
Resources:	

2.2.3 Station 3

E906 will reuse the E866 Tracking Station 3. This task will be done in parallel with 2.2.2.

Lead Institute:	Rutgers
Critical Path:	No
Duration:	6 Months
Start Date:	Dec. 2008
Cost:	$4,000
Resources:	

2.2.4 Station 4

E906 will reuse the E866 Tracking Station 4.

Lead Institute:	Rutgers, Los Alamos
Critical Path:	No
Duration:	6 Months
Start Date:	Dec. 2008
Cost:	$7,000
Resources:	

2.2.5 Station 1 gas mixing and distribution

A fast gas will be used in Station 1 because of high rates. We are planning on using an 80:20 mixture of CF_4:isobutane which will be recirculated. The recirculating system will be taken from the HERMES RICH system which the Argonne MEP group already owns. Fermilab is responsible for the basic "plumbing" of the system and for flammable gas safety. These costs are included in Fermilab's impact assessment [1].

Lead Institute:	Argonne, Fermilab
Critical Path:	No
Duration:	1 Month
Start Date:	Feb. 2009
Cost:	$3,000
Resources:	

2.2.6 Station 2, 3, & 4 gas mixing and distribution

Stations 2, 3 and 4 will run a 50:50 mixture of Ar:ethane. Fermilab is responsible for the basic "plumbing" of the system and for flammable gas safety. These costs are included in Fermilab's impact assessment [1].

Lead Institute:	Argonne, Fermilab
Critical Path:	No
Duration:	1 Month
Start Date:	Nov. 2008
Cost:	$13,000
Resources:	

2.3 Trigger

The trigger system will be, in concept, similar to the E866 trigger system. This system was based on finding "roads" for likely candidate positive and negative muons through the spectrometer in the bend-z plane and in the non-bend-z plane separately. The positive and negative roads were then paired into an event candidate. For E906, this logic will be implemented in a custom FPGA module.

2.3.1 Design

Lead Institute:	Rutgers
Critical Path:	No
Duration:	6 Months
Start Date:	Sep. 2007
Cost:	\$50,000
Resources:	

2.3.2 Prototype

Lead Institute:	Rutgers
Critical Path:	No
Duration:	6 Months
Start Date:	Sep. 2007
Cost:	\$26,000
Resources:	

2.3.3 Testing and Revision

Lead Institute:	Rutgers
Critical Path:	No
Duration:	2 Months
Start Date:	Aug. 2008
Cost:	\$13,000
Resources:	

2.3.4 Fabrication

Lead Institute:	Rutgers
Critical Path:	No
Duration:	1 Month
Start Date:	Feb. 2009
Cost:	\$14,000
Resources:	

2.3.5 Installation and integration

Lead Institute:	Rutgers
Critical Path:	No
Duration:	1 Month
Start Date:	Apr. 2007
Cost:	
Resources:	

2.4 DAQ

The data acquisition will be done within the framework of the CODA system from

JLab. Many members of the collaboration are familiar with the CODA system. Data will initially be stored locally and then spooled to the Fermilab computer center as a background task. The expected data rate is 200 Hz during the 5 s spill for a 1.5 kB event size, or a time averaged 1.5 kB/s.

2.4.1 CODA setup

This is the setup of the Linux-based machine on which CODA will run, installation of the basic software, interfacing with the VME-based ROC's and disk system for local data storage.

Lead Institute:	Argonne
Critical Path:	No
Duration:	4 Months
Start Date:	Jan. 2008
Cost:	$40,000
Resources:	

2.4.2 Test LeCroy 3377 modules

Fermilab Prep electronics pool has sufficient LeCroy 3377 multi-hit TDC's for this experiment. Fermilab does not, however, have sufficient resources to test all the modules before the experiment. Prep has offered to provide a test setup for these units and the collaboration will provide the labor.

Lead Institute:	Argonne, Abilene
Critical Path:	No
Duration:	3 Months
Start Date:	Jan. 2008
Cost:	
Resources:	Fermilab test setup

2.4.3 FERA readout

The LeCroy 3377 units will be read through the FERA bus. Currently, the CODA system has no interface to FERA. We plan to use a FERA to VME interface for readout of these units.

Lead Institute:	Argonne
Critical Path:	No
Duration:	8 Months
Start Date:	Jan. 2008
Cost:	$15,000
Resources:	

2.4.4 Latch readout

For the Station 1 MWPC, Station 4 Prop tubes and the hodoscopes, the experiment will use the Nevis bus system for readout. The electronics and cabling will come from E866 and E871.

Lead Institute: Argonne
Critical Path: No
Duration: 11 Months
Start Date: Jan. 2008
Cost:
Resources:

2.4.5 Integration and testing

Lead Institute: Argonne
Critical Path: No
Duration: 3 Months
Start Date: Jan. 2008
Cost:
Resources:

2.5 Offline Computing

2.5.1 Monte Carlo

A "fast" Monte Carlo program already exists which traces muons through the spectrometer and reconstructs their tracks including effects from multiple scattering and energy loss. A GEANT Monte Carlo tracking all particles through the beam dump/hadron absorber to tracking Station 1 also exists. This would either extend the GEANT Monte Carlo to cover the entire spectrometer or adapt the full E866 Monte Carlo to the new spectrometer.

Lead Institute: Los Alamos, Abilene
Critical Path: No
Duration: 24 Months
Start Date: Jul. 2007
Cost:
Resources:

2.5.2 Analysis

The analysis will be based on the already existing E866 analysis package, which has been maintained for the previous Drell-Yan experiments by Los Alamos. Los Alamos will update this software for the new detector configuration and event format.

Lead Institute: Los Alamos, Argonne
Critical Path: No
Duration: 24 Months
Start Date: Jul. 2007
Cost:
Resources:

APPENDIX A: REQUESTS FOR FERMILAB

In planning for the experiment and the spectrometer upgrade, most of the tasks directly related to the spectrometer upgrade have been take on by the collaboration. There are some areas, however, for which we are specifically requesting that Fermilab take responsibility. These are itemized below.

- Provide slow extracted beam of 120 GeV proton at a rate of no more than $2/time10^{12}$/s for a total of 5.2×10^{18} protons on target in two years.
- Provide beam line and instrumentation.
- Assemble New M1 magnet in MWest area from coils and pole tips supplied by Argonne and return yoke from SM12. This includes providing a suitable foundation for the magnet now that the experiment has been moved to MWest.
- Provide and install beam dump in M1 magnet with necessary water cooling. The E866/NuSea beam dump should be able to be modified for this.
- Modify SM12 flux return steel as necessary for new magnet. This specifically includes cutting the steel blocks on the top and bottom of the magnet since the new magnet is narrower than SM12.
- Install SM3 in MWest. Again, This includes providing a suitable foundation for the magnet now that the experiment has been moved to MWest.
- Provide magnet power supplies.
- Provide utilities (power and cooling water) for magnets and power supplies.
- Install muon ID absorber walls using material from E866/NuSea.
- Provide liquid hydrogen and deuterium targets and drive mechanism to interchange solid and liquid targets remotely. If the E866/NuSea targets and drive mechanism are still available, these would also work for E906/Drell-Yan.
- Provide PREP electronics for the experiment. Specifically, this consists of the E866 PREP electronics plus 1700 channels of multi-hit TDC (LeCroy 3377) and 32 channels of mean timers.

- Provide chamber gas distribution system plumbing
- Provide flammable gas safety system.
- Provide appropriate radiation shielding, radiation safety interlocks and handle all aspects of radiation safety monitoring.
- Provide rigging for installation.
- Provide counting house and electronics areas with appropriate utilities and networks installed.
- Provide facilities for scintillator and light guide fabrication.
- Provide equipment staging areas as needed for the assembly of the spectrometer.
- Provide two analysis workstations for counting house.

[1] D. Christian et al., *Estimated cost to mount E906* (2006), unpublished.

[2] D. Christian et al., *Report of the "Meson Beam Task Force"* (2006).

[3] G. Moreno et al., Phys. Rev. **D43**, 2815 (1991).

[4] C. A. Gagliardi et al., Nucl. Instrum. Meth. **A418**, 322 (1998).

[5] Y.-C. Chen (2001), private communication.